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WATER-FLOODING OPPORTUNITIES EXPLORED BY GAS INJECTION

By

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Water-Flooding

Opportunities Explored by

Gas Injection

By FREDERICK SQUIRES

EXPLORING and determining the continuity of sands through the use of high-pressure gas injected through selected wells offers a means for determining relative permeabilities, and also suggests a method for optimum drilling conditions for further development of known shoestring sands. The author demonstrates the technique with maps of water-flood areas, and outlines procedures adaptable for like conditions. This paper is printed by permission of the chief, Illinois State Geological Survey.

IN MANY Illinois oil fields gas-repressuring will be followed by water-flooding. A knowledge of the continuity of the sands and their permeability will be important in choosing areas that are favorable for flooding. The present investigation was undertaken to find methods for obtaining this important information. Gas injection itself proved the best tool.

The relative degree of permeability of the oil sands of a pool is indicated by (1) the initial productions of its wells and (2) the rate of travel of injected gas. The accuracy of the first is limited by the fact that a well's initial production is influenced by the time of drilling in relation to the time of drilling other wells in the same pool. The travel of injected gas is a more reliable measure because the tests may be made simultaneously under the control of the investigator.

The relative permeabilities of the sand between an input well and each of its surrounding output wells may be measured by the time required for injected gas to travel each of the intervening distances and by the volume of gas issuing from each of the output wells.

The direction and extent of permeable areas, and probable producing areas beyond drilled areas, may be indicated by shutting in all the wells, raising the pressure on the whole pool by means of gas injected into the center, and recording the pressure and the rate of pressure decline on each of the shut-in output wells. Wells nearest to undrilled permeable areas will not reach as high pressure and will lose pressure faster than the wells nearer the outer limits of a permeable sand.

The relative permeability of the sands around different input wells may be measured by the difference in the amount of pressure required to inject the same volume of gas into each.

The continuity of a sand may be determined by injecting a tracer gas into an input well and recovering it from output wells.

The foregoing introductory statements are treated more fully in the following text. They are illustrated by a map of Crawford County showing all its repressured areas, a typical repressuring project on which sand permeabilities are measured by forcing gas from input through surrounding output wells; graphs on pressure-volume relationships showing the method of measuring sand permeability around input wells; a table of input wells with the pressures required to inject equal volumes per day as a comparison of permeabilities in different areas; a repressured project on which permeability determinations both by core analyses and input pressure-volume relationships have been made in order to relate the two methods; contours on the same area drawn from pressure-volume relationships; a diagram showing the method of exploration beyond drilled areas; and a diagram illustrating a test for continuity of stratum.

The map of Crawford County (Figure 1) shows the areas of Robinson sand production and marks the parts which have been repressured. The average sand thickness is 20 feet. All the investigations treated in this paper have been confined to this county.

Permeability Measured by Volume of Output Gas

Figure 2 contains contours to show the volumes of injected gas produced simultaneously from output wells. As between wells equidistant from an input well, the permeability of the intervening sand varies directly as the volumes of gas traveling from the input well to each surrounding output well. A closer correspondence between the contours and the variations of permeability would have resulted if each input well had been operated alone, which would have avoided competition with neighboring input wells.

Later in the life of the wells, volumes would increase under the same pressure because the smaller amount of liquid in the sand would increase its permeability to gas. However, sand areas originally more permeable than others would become more so as time passed.

Relative permeabilities of the sand between input and surrounding output wells may be measured by speed of travel of injected gas. When injection is begun on a new operation the time required for injected gas to reach each output well is noted and a map of the area is contoured with lines representing equal time intervals. The resulting picture gives measurements of relative permeabilities.

This may be done at any later time by using a tracer gas, noting the time of

FIGURE 1. Oil-producing areas of Crawford County, Illinois, showing areas of repressuring.

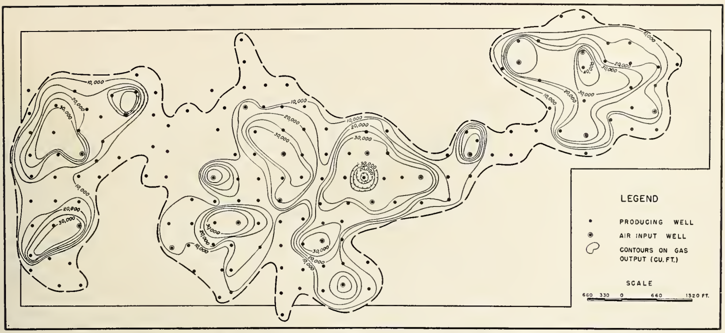

FIGURE 2. A repressured area in Crawford County, Illinois, with contours showing equal volumes of gas output per day.

arrival of the tracer at the output wells, and drawing a contour map as above. Air is a good tracer gas, as are carbon dioxide, helium, and many others.

The tests shown in Figure 2 are suggestions for a method rather than examples of an ideal performance. It is clear that these methods measure the average permeability of the sand body and do not indicate vertical variations in the permeabilities of the sands tested. Such vertical variations may be measured in any input well by filling the sand bore, foot by foot, with a removable seal and measuring the input volumes produced by uniform pressure for each of the diminishing areas of exposed hole. From such records the relative permeability in terms of volume rate of injection of gas may be figured for each foot of sand.

Extent of Permeable Areas Beyond the Drilled Portion

The direction of the extension of permeable and therefore probably productive sand beyond the drilled area may be tested by closing in the casingheads of all output wells, creating a high artificial pressure on the sand through a central input well, and observing the immediate pressure and the rate of pressure decline at each well. The pressure will decline in the direction of the outside areas of permeable sand beacuse the injected gas will escape from the drilled areas into them in an effort to establish equilibrium.

This method was successful in showing the connection between isolated pools in the Cow Run sand in southeastern Ohio. It is most dependable on highly permeable shoestring sands that have little natural rock pressure. The process is noted in Patent 1,168,757, issued to Frederick Squires, by the claim "The method of determining the location and probable direction of extent of gas or oil-bearing strata which consists in sinking three or more wells to such strata at relatively remote points, creating an artificial pressure at one well which shall be observable at the other wells, when the wells communicate with a common stratum, and recording the pressures at all of the wells, whereby the flow of the fluids in the stratum is indicated."

TABLE 1

Pressures Required to Inject 20,000 Cubic Feet Per 24 Hours Into Certain Wells in Crawford County

(In pounds per sq. in.)

Location	PSI	Location	PSI
5-5N-12W...	24.0	10-7N-13W...	22.5
6-5N-12W...	90.0	10-7N-13W...	28.5
6-5N-12W...	42.0	10-7N-13W...	26.5
2-5N-13W ..	43.0	10-7N-13W...	24.0
2-5N-13W...	53.5	10-7N-13W...	26.5
16-6N-13W...	17.5	10-7N-13W...	24.0
22-6N-13W...	39.5	10-7N-13W...	15.5
22-6N-13W...	166.0	10-7N-13W...	59.0
22-6N-13W...	84.0	10-7N-13W...	15.0
23-6N-13W...	90.0	10-7N-13W...	21.5
23-6N-13W...	113.0	10-7N-13W...	80.0
23-6N-13W...	76.0	10-7N-13W...	102.5
27-6N-13W...	30.0	10-7N-13W...	19.5
28-7N-12W...	56.0	10-7N-13W...	36.0
34-6N-13W...	20.5	10-7N-13W...	28.0
9-7N-12W...	13.5	10-7N-13W...	50.5
9-7N-12W...	82.0	10-7N-13W...	18.0
9-7N-12W...	95.0	*10-7N-13W...	25.0
9-7N-12W...	210.0	11-7N-13W...	26.0
9-7N-12W...	260.0	16-7N-13W...	72.0
9-7N-12W...	245.0	16-7N-13W...	172.0
9-7N-12W...	86.0	18-7N-13W...	34.0
9-7N-12W...	155.0	18-7N-13W...	23.0
10-7N-12W...	113.0	18-7N-13W...	67.0
10-7N-12W...	116.0	19-7N-13W...	84.0
10-7N-12W...	110.0	19-7N-13W...	74.0
11-7N-12W...	21.0	20-7N-13W...	99.0
11-7N-12W...	193.0	20-7N-13W...	74.0
18-7N-12W...	28.5	21-7N-13W...	55.5
8-7N-13W...	200.0	21-7N-13W...	60 0
8-7N-13W...	112.0	24-7N-13W...	34.0
8-7N-13W...	160.0	24-7N-13W...	19.5
9-7N-13W...	26.0	29-7N-13W...	140.0
9-7N-13W...	38.0	30-7N-13W...	92.0
10-7N-13W...	13.0	11-7N-14W...	75.0
10-7N-13W...	19.5	12-7N-14W...	64.0

* Core analysis on this well gave an average permeability of 165 M.D.

The pressures imposed on input wells and the volumes of gas injected at these pressures have been recorded at regular intervals on many repressured properties. The pressure and corresponding volume input rate for each well usually changes, due in some cases to the fact that the operator begins with low pressures in order to avoid the danger of bypassing and later increases the pressures as he becomes more familiar with the characteristics of his property. The pressures and corresponding volume input rates for a single well may be plotted on a graph. If log-log graph paper is used the points generally fall into a straight line pattern which may be easily extrapolated (Figure 3).

In order to compare permeabilities in different wells it is necessary to determine for each well either the pressure required to inject gas at a standard rate or the rate of gas injection at a standard pressure. Of these two possible methods the first was chosen as the more convenient. A standard input rate of 20,000 cubic feet of gas per day was selected and the pressure necessary for this input for each well was determined from the graphs.

It will be understood that this method gives general and not accurate, specific information. It is believed, however, that its application will be useful in dividing repressured areas into permeability classifications which will answer some of the questions which will arise in the minds of operators looking for floodable territory. Such information may then be supplemented by coring and core analysis.

Very few core analyses are available for Crawford County but three of these

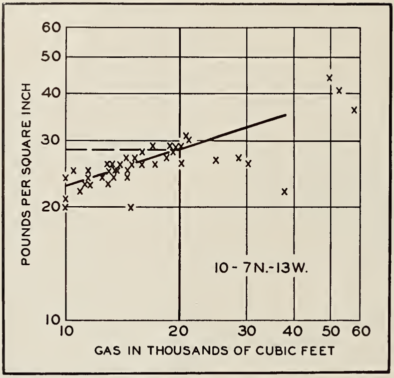

FIGURE 3. Graph of a set of observations on a single well, showing rate of gas intake in thousands of cubic feet per day for various pressures.

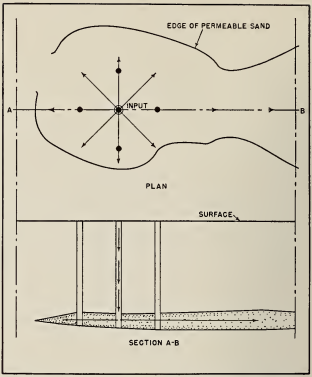

FIGURE 5. Test for permeable sand beyond drilled area.

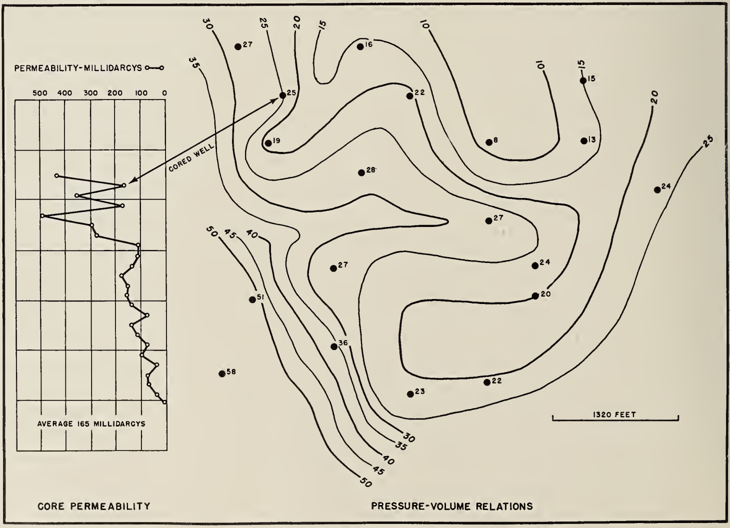

FIGURE 4. A repressured area in Crawford County, Illinois, with contours showing equal pressures in pounds per square inch required to inject gas at a standard rate of 20,000 cubic feet per day as determined from graphs like that shown in Figure 3.

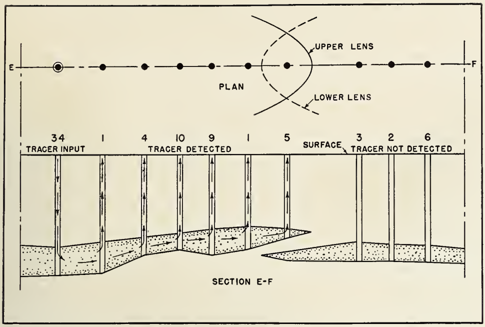

FIGURE 6. Use of tracer in gas to detect discontinuity of sand.

are from an area on which there are records of pressure-volume relationships for a large number of input wells. It is therefore possible to compare these two methods of measurement and to relate the results to other territory on which there are only pressure-volume records.

One core analysis was made for a well drilled to serve as an input. The analysis shows an average permeability of 165 millidarcys. The results of this analysis are shown in Figure 4. Afterward this well took 20,000 cubic feet of gas per day at a pressure of 25 pounds per square inch.

All the input wells in the immediate vicinity were graphed for pressure-volume relationship. The pressures found were set down on a map (Figure 4) and contours showing equal pressures were drawn. The result shows an interesting gradation of permeability from high at the northeast to low at the southwest.

As a cored well with an average permeability of 165 millidarcys required a pressure of 25 pounds per square inch to inject 20,000 cubic feet of gas per 24 hours, it is fair to assume that input wells which required higher pressures were in less permeable sand than an average of 165 millidarcys, and that wells which required lower pressures for an equal input rate were in more permeable sand than the well in question.

Since this is true in the area contoured it is equally true in other parts of Crawford County.

Permeabilities by Pressure for Different Areas

Table 1 shows the pressures required to inject 20,000 cubic feet of gas per day in the input wells listed. From it the general degree of permeability of the sand at the input well may be inferred. Only a few of the many Crawford County input wells are used. The investigation could be extended to cover the whole territory. It will be useful in getting general ideas about well spacing and required water pressures for flooding when studied by contours, as shown in Figure 4. Such widespread permeability studies may throw some light on sedimentation.

Exploration Beyond Drilled Areas

Some of the shoestring sands in southeastern Ohio are narrow and winding, as though laid down in ancient river beds. Oil was first found in isolated areas but later the areas were connected by drilling. The winding nature of the productive area and the extremely narrow connecting links between wider pools resulted in drilling many dry holes.

In several areas the practice of exploring with gas injection suggested the direction in which to extend the pools in order to connect them up to other pools with fewer dry holes. The practice is illustrated in Figure 5, which shows a diagrammatic layout of five wells, the central one of which is an input well and the others normally output wells. The process of exploring with injected gas consists of shutting in all the output wells, raising the pressure on the area through injection of gas at the input, reading the pressure on all the wells immediately and then at regular intervals thereafter. If the shoestring sand extends beyond the drilled area it will bleed off the gas and thereby lower the pressure most at the well nearest to the extension. New drilling is indicated in the direction beyond the well that shows the least original pressure and the fastest drop in pressure. Where production was found by this means the new wells showed that the sand had been invaded by the gas; it was shown by their initial production, by tendency for oil to rise in the hole, and by the large volume of gas produced with the oil.

Conditions like those presented by the Cow Run sand in southeastern Ohio are well adapted for such exploration. The fact that the sand lenses out at the sides, that it is highly permeable, has little or no rock pressure, and exists in narrow continuous winding bodies, all simplify the use of injected gas for the purpose. The method may be applied in other fields.

Test for Sand Continuity by Tracer Injection and Recovery

The water-flood operator must be sure the sands are continuous over the areas he intends to flood. This is easily tested in gas injection territory. Sand must extend from well to well if gas has traveled between them. If there is any doubt as to whether the gas issuing from a well is native to the formation or is injected gas, there are many tests to remove the doubt. Tracers may be used in the injected gas and detected at the output wells when input and output wells are in a continuous stratum. Their presence in output gas is a sure evidence of throughput. Air is a good tracer because output gas containing air may be checked for oxygen with an Orsat equipment. Carbon dioxide is another test gas, and there are many more.

Figure 6 shows a condition that is fatal for flooding, but one that can be easily detected in advance by injecting tracer gas.

Summary

The methods described may be used by the water-flood operator to gain a general knowledge of sand permeabilities in gas injection territory. What the methods lack in exactness they make up for in the vastness of the areas they are able to cover.

This is only a beginning. It is hoped that others will give expert thought to perfect the methods here suggested until they provide a more exact relationship between sand permeabilities derived from gas injection and sand permeabilities established by core analyses, and that they will develop a method by which permeabilties found by injected gas may be translated into permeabilities to be encountered in water injection.

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